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Air Leakage and Thermal Performance of a Mark III Relocatable Lewis Building

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Building Environment Division
Center for Building Technology
Institute for Applied Technology
National Bureau of Standards
Washington, D. C. 20234

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Final Report

Prepared for
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U.S. DEPARTMENT OF COMMERCE, Elliot L. Richardson, ***Secretary***

Edward O. Vetter, ***Under Secretary***

Dr. Betsy Ancker-Johnson, ***Assistant Secretary for Science and Technology***

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ABSTRACT

This report presents the findings of air leakage and heat transfer tests of a Mark III relocatable building at the National Bureau of Standards, Building Environment Division, for the U.S. Department of the Navy. Quantitative and qualitative (smoke trace) air leakage tests with the building pressurized, and the heat transfer test, were performed with the building erected in an environmental laboratory. The quantitative air leakage tests were performed in two phases. One was with the building racked to simulate a wind load and the other was without racking. The building was of prefabricated honeycomb panel construction using aluminum skins. Included are photographs of the building and test equipment and tables and charts showing the magnitude of air leaks at the windows and doors. Racking had negligible effect on the air leakage rate.

Key Words: Air leakage of buildings; building heat transfer; honeycomb panel construction; relocatable buildings; wind load racking.

Table of Contents

List of Figures

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1. Introduction

This report presents data from the first part of a series of tests to develop information to be used to improve the properties of a redesign of the relocatable Lewis building. The purpose of this report is to present results of air leakage rate and thermal performance tests of a Mark III relocatable Lewis building.

The thermal performance tests of a Navy relocatable building were sponsored by the Naval Facilities Engineering Command and coordinated by the Naval Civil Engineering Laboratory at Port Hueneme, California. The tests reported within this report were conducted in the environmental chamber of the Building Environment Division at the National Bureau of Standards.

The data was obtained from tests of a specimen consisting of two bays of a normal three-bay building erected in an environmental chamber at the National Bureau of Standards. The erection of the two bays of the Mark III building was on a concrete foundation simulating the recommended field installation.

The tests were to determine the rate of air leakage from the building with and without a racking load, and to determine the paths of air-leakage by using smoke tests. Section 7, discusses possible material changes to reduce the Mark III building's thermal conductance properties.

The smoke test procedures and results are discussed, and some photographs of the smoke tests are included. The same format is used to present the procedures and results of a heat transfer test of the building.

The air leakage data has been summarized in table form, and photographs of the equipment used are included. The calculations of all the air leakage rates found in Tables A and B were partially accomplished with the aid of OMNITAB, a computer program for routine calculations. Air leakage data were obtained by measuring the air flow rate required to maintain a small pressure difference between the inside and outside of the building. The air leakage information provided can be used as a comparison with test results of future and past building designs.

2. Test Specimen Description

2.1 General

The test specimen was a Mark III relocatable Lewis building of honeycomb sandwich panel construction with aluminum skins and aluminum extrusion frame members.

2.2 Foundation and Floor

The building was erected on a concrete foundation supporting the building at nine points, i.e., each corner, mid-point of the exterior walls, and one in the center for the floor area. The floor area of the two-bays-test-specimen erected in the 3-story, 2100 square foot environmental chamber was approximately 671 square feet.[1] The dimensions of the base were 31 ft. 11 1/2 inches by 19 ft. 8 inches. The foundation was made so that it simulated the proposed nine pier support system to be used in the field. Special sections of the concrete foundation were used to mount apparatus to apply the roof loads and simulated wind load. This equipment was used by the group studying the mechanical properties of the structure covered in other reports [1] and [2]. These extra foundation areas did not interfere with the building properties covered in this report. Figure 1 shows the foundation and partially constructed building.

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[1] Conversion factors to International System of Units (SI) are given at the end of this report.

The base of the building was constructed of aluminum I-beams connected to the concrete at the nine support points. These beams supported the flooring panels. The floor panels were not further sealed against air leakage beyond the tongue and groove joints provided at the top and bottom surfaces of the mating edges of the panels.

2.3 Wall and Roof

Each building end contained a panel with a door and a panel with a window. One side of the building was assembled using three window panels and the opposite side was assembled using only plain wall panels. Figure 2 is an end view of a section of a wall panel. Aluminum channel extrusions were affixed to the flat floor with the open ends facing up. The side panels rested in the channels and screws were used to anchor the aluminum-skinned side panels. The vertical joints between the side panels were mechanically connected and partially sealed with a plastic extrusion.

Aluminum extrusions were screwed on top of the wall panels to form the mechanical connection between the building sides, eaves, and roof.

The roof was supported by the sides, eaves, and two beams that ran logitudinally down the middle of the building. The roof panels were joined together in the same manner as the side panels.

Certain of the wall panels, as they were supplied, came with built-in windows and doors. Figures 3 and 4, respectively, show a typical door and window assembly. A vinyl latex caulk was applied to all the horizontal joints between panel skins and aluminum extrusions, but no sealer was used where vertical panel to panel joints were made with the plastic connector strips. The seams between adjacent wall and roof panels had no sealer applied after assembly.

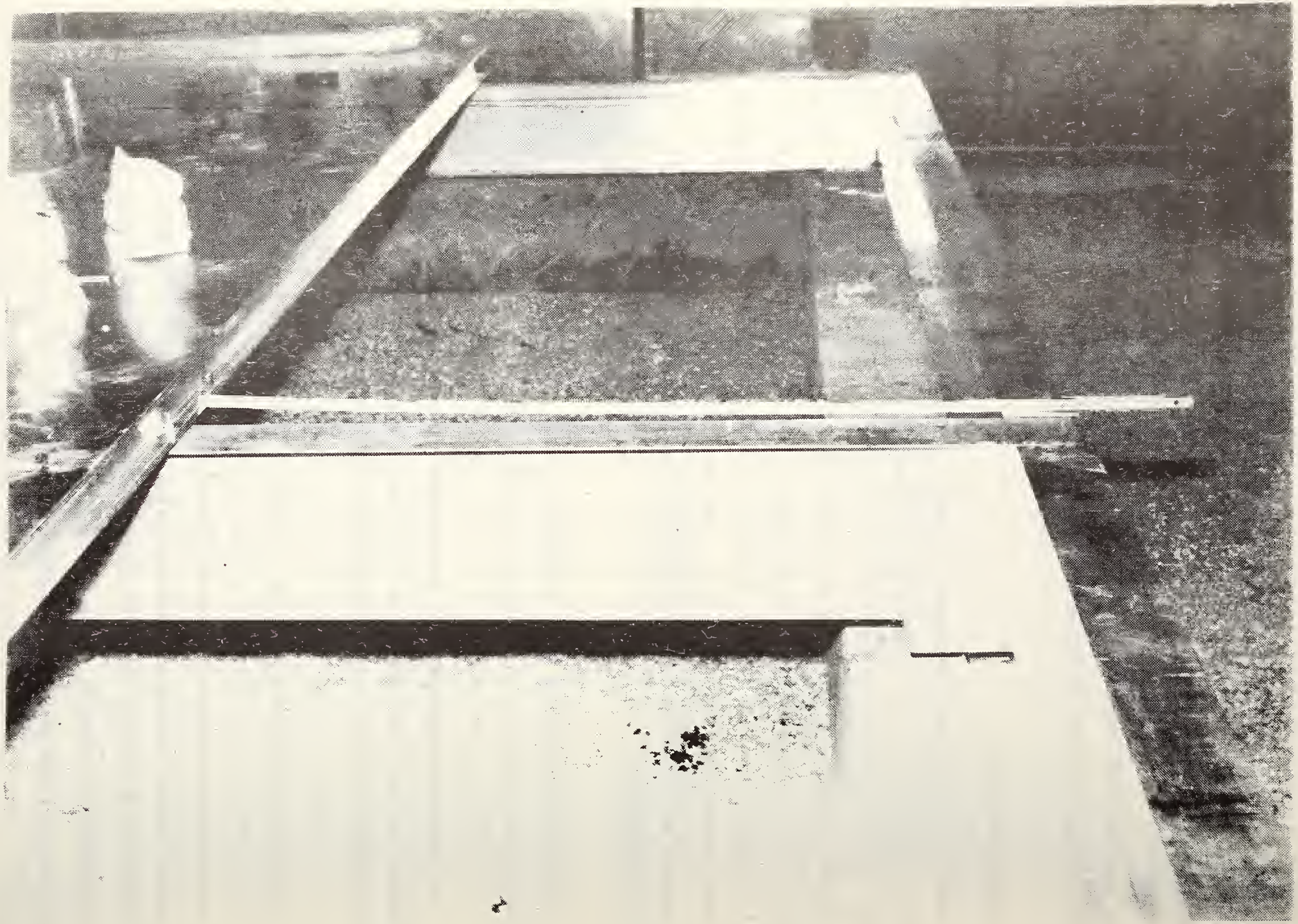


Figure 1   Partially Constructed Building

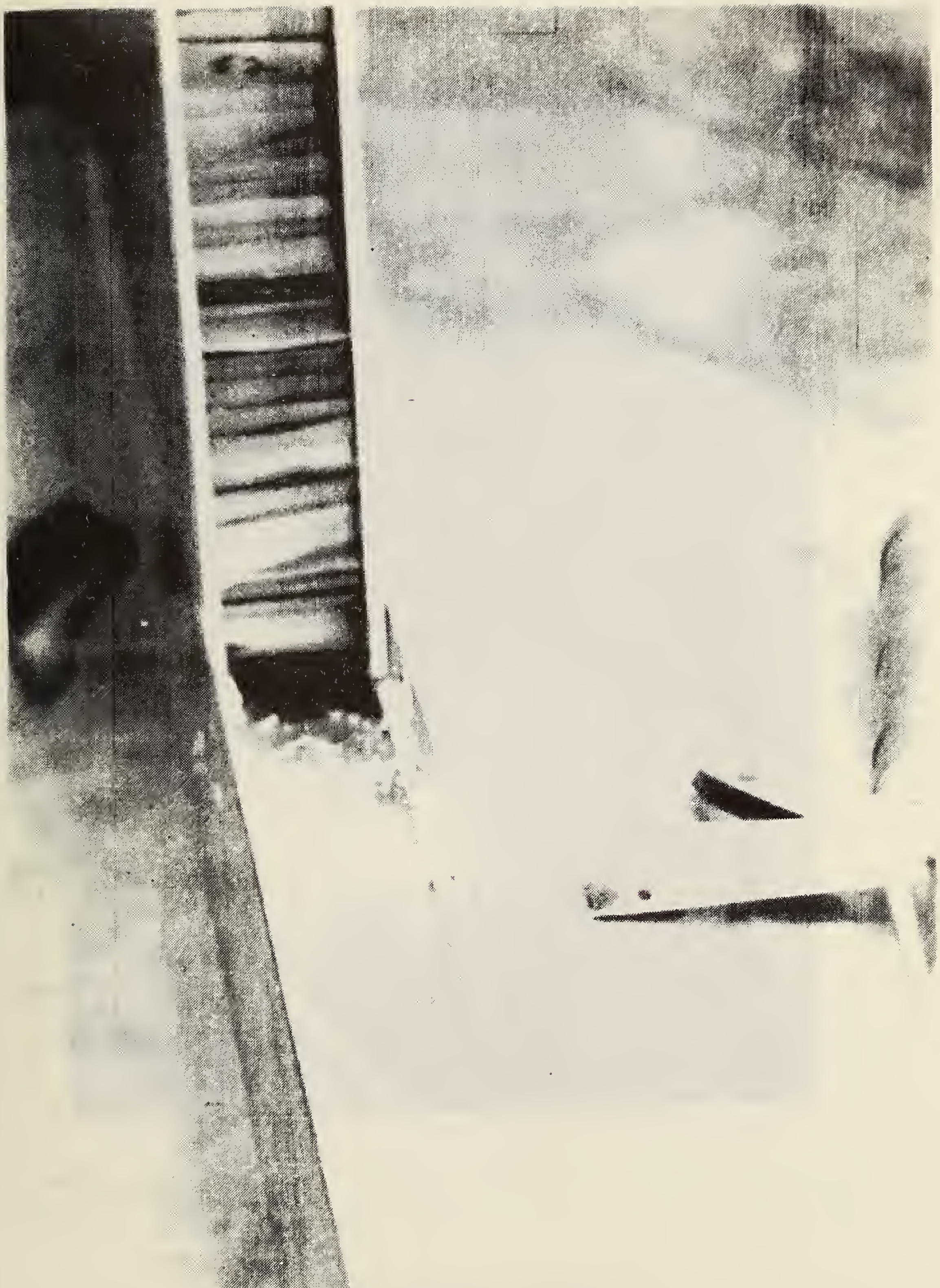


Figure 2. Wall Panel Detail

Figure 3. Typical Door Installation

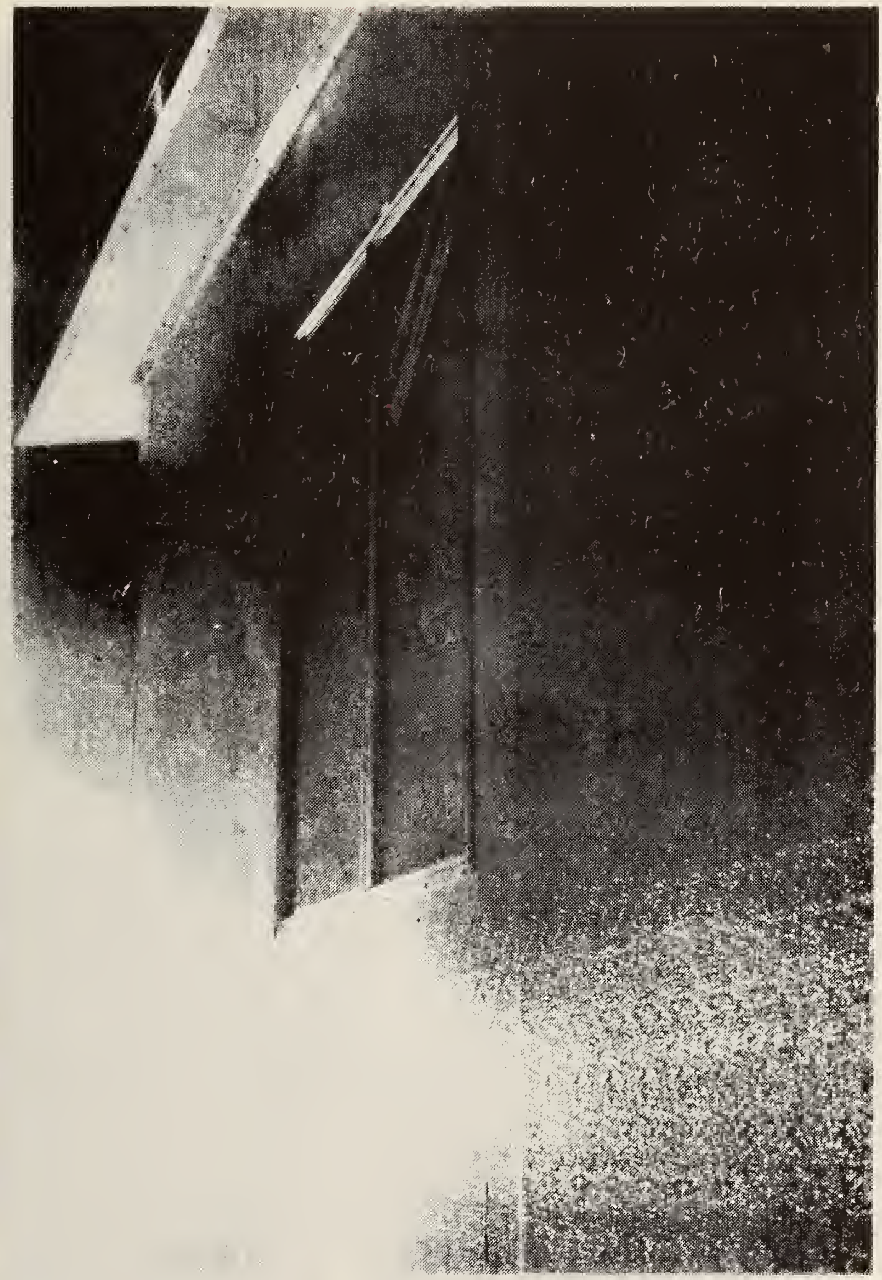


Figure 4. Typical Window Installation

3. Smoke Tests

3.1 General

The purpose of the smoke tests was to indicate the major sources of air leaks by visual means. For five of the smoke tests the building was pressurized by forcing air in; and for two there was no pressure other than that created by the smoke generators themselves. When the tests were performed a fan was always directed at the smoke generators to distribute the smoke throughout the building interior. For these tests pyrotechnic white smoke generators were used. The white smoke completely filled the building within a minute after ignition for both types of smoke tests.

Preliminary tests were used to determine the suitable techniques to photographically record the leaks. Sixteen-millimeter color motion pictures, color slides, and black-and-white and color negatives were used in attempts to record the more significant air leaks. Figure 5 shows white smoke leaking around the rear door.

3.2 Smoke Leaks

The most obvious air leaks were around the doors and around the sliding windows. Figure 6 shows smoke coming out under the front door. Smoke leakage can also be seen in figures 3 and 4. The vertical seams between side panels and the seams between the roof panels were the next most obvious leaks. They were particularly noticeable when the doors and windows were covered on the inside with a sheet of polyethylene film. See figures 7 and 8 for photographs of the method of sealing the windows and doors. Figure 9 shows smoke leakage with windows sealed and with .01 inches W.G. pressure differential.

Figure 5. Smoke Leaks at Rear Door

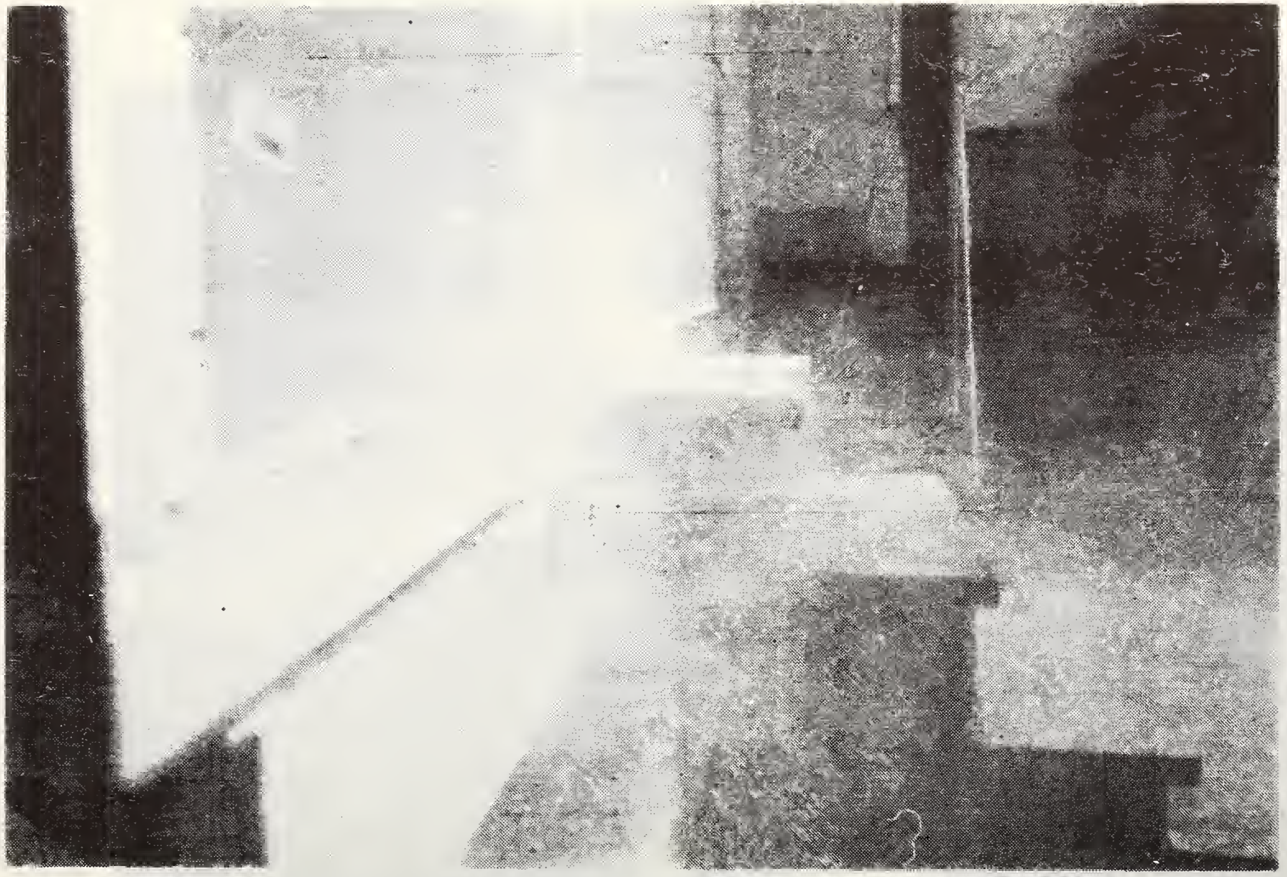


Figure 6. Smoke Leaks at Front Door

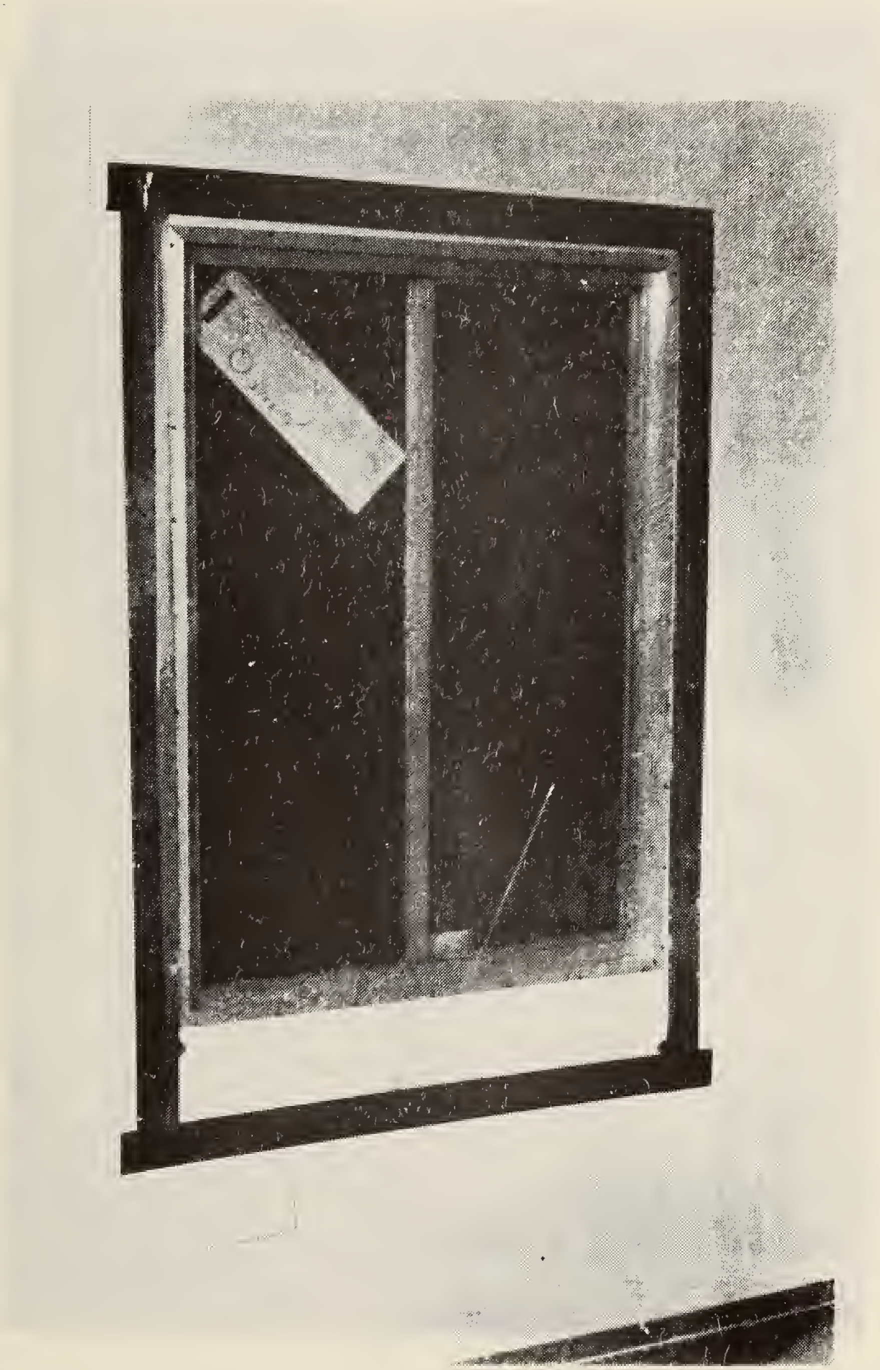


Figure 7. Method Used to Seal Windows on Internal Surfaces

4. Air Leakage Tests

4.1 Instrumentation

During the initial building air leakage tests the windows were pushed closed as tightly as possible and latched. The fit was such that the windows could move about 1/8 inch in their slides. There were fans located in the building and around the outside area, but none of them were turned on during the air leakage tests. They were used only during the smoke tests and immediately after the smoke tests to hasten the clearing of the smoke from the environmental chamber.

The building was pressurized by forcing air in through a measuring orifice. The orifice pipe assembly used to measure air flow was introduced into the building through a hole cut in the center of a window glass so that the least change in building properties would be made by the test apparatus. The tape visible on the glass in figure 10 is an air-tight duct tape that was applied to the glass area for safety on the weakened window pane and as a flexible sealer between the glass and the air pipe.

The manometer, connecting tubes, and their joints were tested by applying near maximum pressure allowed by each manometer and clamping the tube shut. The tubing held the applied pressures for an extended time period, indicating no significant leak was present. During the preliminary smoke tests no leakage was observed in the area around the hole in the glass. The air supplied to the building was taken from the laboratory compressed air supply.

The instruments used to measure air flow are shown in figure 10. The air flow measuring device used was a flat plate orifice flow meter with 2" ID stainless steel meter tube and an ASME standard circular plate orifice of β = .60 size[3]. The pressures across the flat plate orifice were measured by using two "U" tube manometers with each referenced to atmosphere. The up-stream pressure was measured by a mercury manometer with 1 mm increment scale. The downstream manometer had a range of zero to 50 inches W.G. in .1" increments.

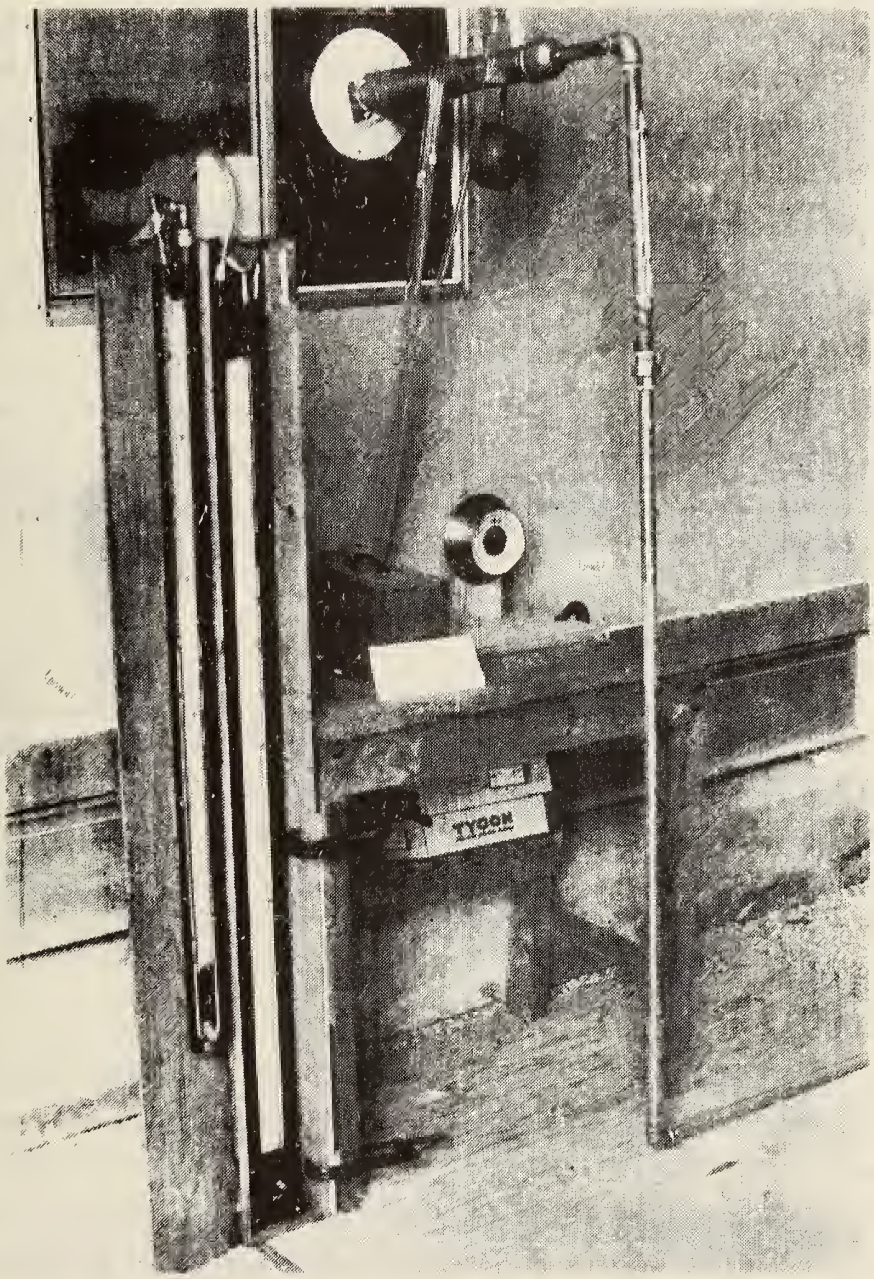


Figure 10. Air Flow Measurement Apparatus

Static pressure differences across the building wall were measured using two pressure taps of similar construction placed at the same absolute elevation with one inside the building and one outside the building. The height of the static pressure bulbs was 41 inches above the building floor. The manometer used for this measurement was a micromanometer with a range of zero to 1.25 inches W.G. in .01 inch increments.

The air temperature in the orifice tube was measured with a thermometer placed on the air line 22 inches ahead of the orifice pipe.

The decorative ceiling trim pieces which are supported between the longitudinal roof beams in the building and which are optionally removable, were both in place for the air leakage tests with and without racking.

4.2 Air Leakage Test Results

The air leakage tests were performed in three stages. The first series of building air pressures was on the building as erected. The second and third series of air leakage versus air pressure runs were performed with the building altered respectively by sealing all the windows and then windows and doors with a polyethylene film as shown in figures 7 and 8.

For the air leakage tests the differential pressures used were .04, .06, .08, .10, and .12 inches W.G. The air leakage corrected to standard cubic feet per minute is presented in Table A, with the pressure differences and corresponding degrees of building sealing listed. Figure 11 is a graph of the air leakage with different polyethylene film sealing. When comparison of this building data with other buildings of the same type is done in the future, the care and degree of caulking both structures must be duplicated as nearly as possible.

BUILDING AIR LEAKAGE

TABLE A

House Sealing Plastic Film Application	House Air Pressure Difference Inches W.G.	Air Flow Standard cfm
No Sealing	.04	103
	.06	135
	.08	172
	.10	196
	.06	133
Windows Sealed With Polyethylene Film	.04	97
	.06	122
	.08	148
	.10	171
	.06	126
Windows and Doors Sealed with Polyethylene Film	.08	92
	.10	108
	.12	121
	.08	93

AIR LEAKAGE vs HOUSE AIR ΔP

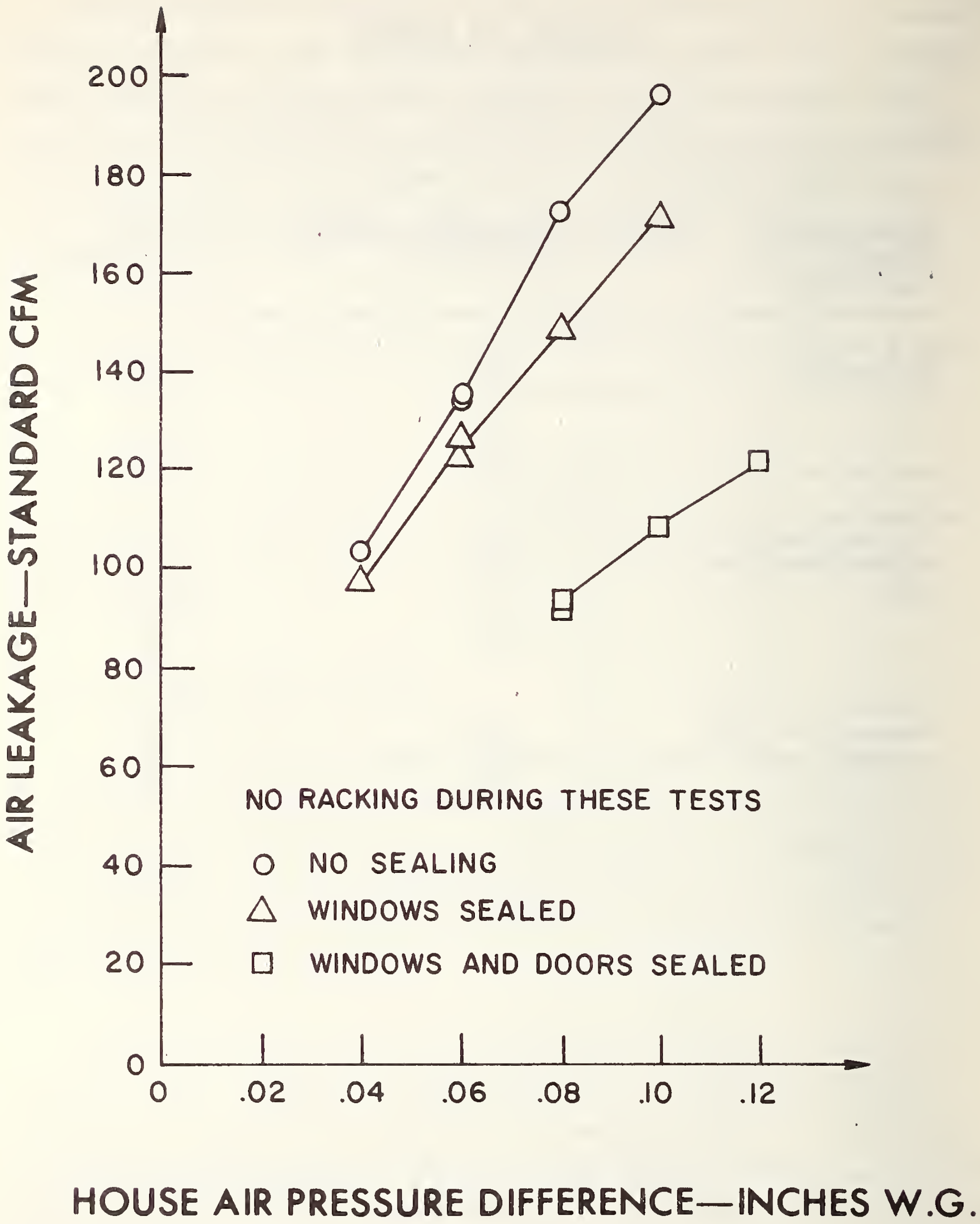


Figure 11.

4.3 Discussion of Results

Previous unpublished studies at the National Bureau of Standards have developed a suggested upper limit for air penetration rates for a wall system of the aluminum skin type. The suggested upper limit was 0.9 CFH/ft^2 for a wall ΔP of 0.10 inches of water at isothermal conditions.

To compare this suggested upper limit based on walls only with the observed leakage of the total building structure of the Lewis building requires an assumption that the total roof, wall, and floor areas approximate an equivalent area of wall only. The area of the floor, roof, ends, and sides including the doors and windows is approximately 2240 square feet. The suggested upper limit air penetration rate times this equivalent wall area gives a suggested upper limit of 2016 CFH for the test building assembled in the NBS laboratories.

Comparing the data from the test of the Lewis building (with the windows and doors sealed with polyethylene to approximate an all-wall condition) at a wall ΔP of 0.10 inches of water and isothermal conditions with the suggested upper limit indicates an air leakage rate of 3.2 times the suggested value for this type of wall construction. It should be noted that some walls of aluminum skin with paper honeycomb core construction previously tested at the National Bureau of Standards have had air penetration rates equivalent to six times the suggested value.

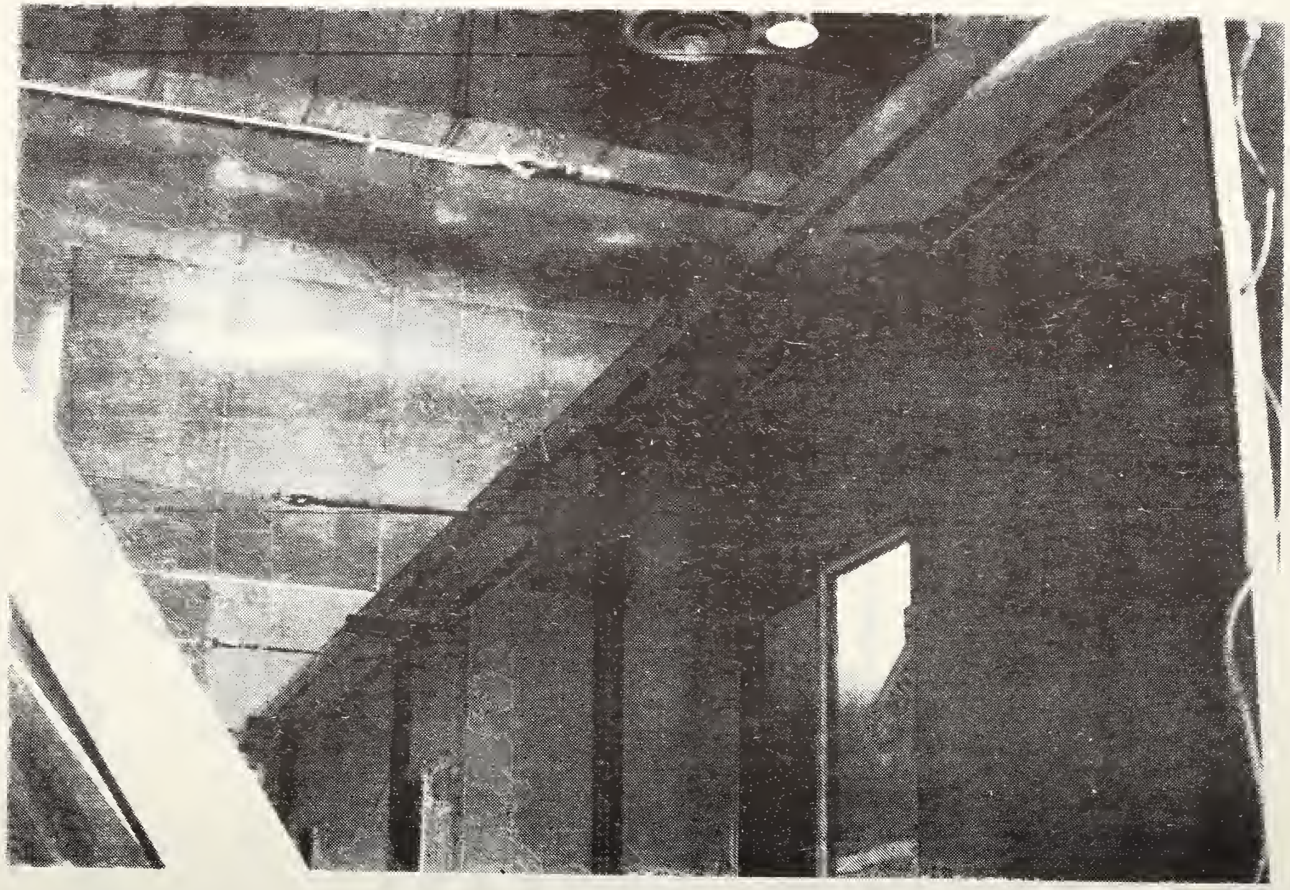


Figure 12. Method of Applying Racking Load

5. Air Leakage During Racking

5.1 Building Preparation

A series of air leakage tests were performed during racking of the building to simulate wind deflection effect. Prior to the racking test and after the air leakage tests previously described, four holes were cut in the walls of the house near the roof joint to attach the load-applying equipment to the building wall. A fifth hole was cut through a wall panel to pass strain gage indicator wires to the outside of the building. These openings were carefully caulked. During the racking test the windows remained sealed with polyethylene film left in place from the previous air leakage tests, but the doors were unsealed. The windows were left sealed because their design was to be changed on later model buildings and their leakage effect was not desired in the data. This will allow valid air leakage comparisons with later buildings.

The racking forces were applied to the building by four hydraulic devices connected to the building by cables, wood 2 x 4's and eye bolts as shown in figure 12 and described in detail in another report [2].

5.2 Air Leakage During Racking Test Results

For comparison with the previous air leakage tests, air flows were measured at four pressure differences, 0.04, .06, .08, and .10 inch W.G. without racking. Then, for ten cycles, the building was racked to .629 of the design load and returned to a no-load condition. The definition of the design wind pressure is a wind-loading equivalent to 25 lb/ft^2 on the side of the building as described in another report [2]. An air pressure difference of 0.10 inches W.G. was then held constant for the remainder of the test. The air leakage, in standard cfm versus the degree of racking is presented in Table B. Figure 13 is a graph of air leakage versus pressure difference prior to and during racking, after installation of the racking apparatus.

Two small air flow excursions occurred at 0.377 and .755 rack ratios. The differences from the air flow at the start of the test of 6 and 1 standard CFM are not too large when the capabilities of the air flow metering system are analyzed. The measuring system has a tolerance of 2% of the total flow considering the conditions during the tests and the limits of the tables used for calculation.

TABLE B

RACKING TEST BUILDING AIR LEAKAGE

WITH WINDOWS SEALED

House Air Pressure Difference Inches W.G.	Air Flow Standard cfm	Racking Loads* Ratio	Time of Reading Air Flow Hour	Min.	
.04	94	0.000	0	00	(start of test)
.06	118	0.000	0	03	
.08	153	0.000	0	05	
.10	176	0.000	0	29	
		**			
.10	176	0.000	0	45	
.10	176	0.126	0	51	
.10	176	0.252	0	55	
.10	182	0.377	0	58	
.10	176	0.503	1	00	
.10	176	0.629	1	03	
.10	175	0.755	1	06	
.10	176	0.881	1	10	
.10	176	1.005	1	16	
.10	176	1.131	1	21	
.10	176	1.26	1	26	
.10	176	1.26	1	30	
.10	176	0.76	1	34	
.10	176	0.50	1	36	
.10	176	0.00	1	41	
.10	176	0.00	1	46	(end of test)

* Racking Loads and Ratio of (Load)/(Design Load).

** Building cycled to 0.629 of design load ten times. Design load is a wind load of 25 lb/ft^2 on the side of the building.

RACKING TEST AIR LEAKAGE vs HOUSE AIR ΔP
WITH WINDOWS SEALED

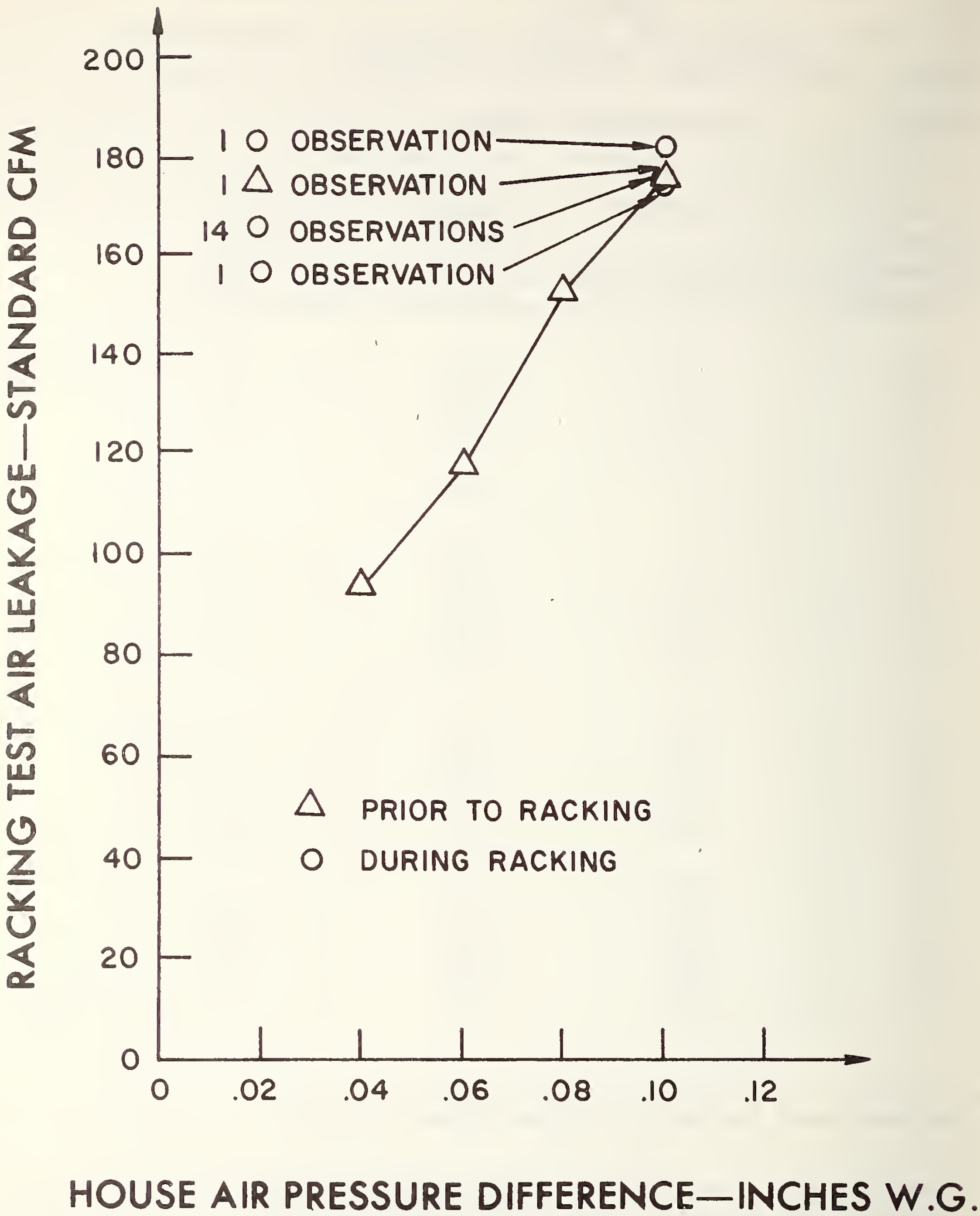


Figure 13 Racking Test Air Leakage vs House Air ΔP with Windows Sealed

6. Heat Transfer Test

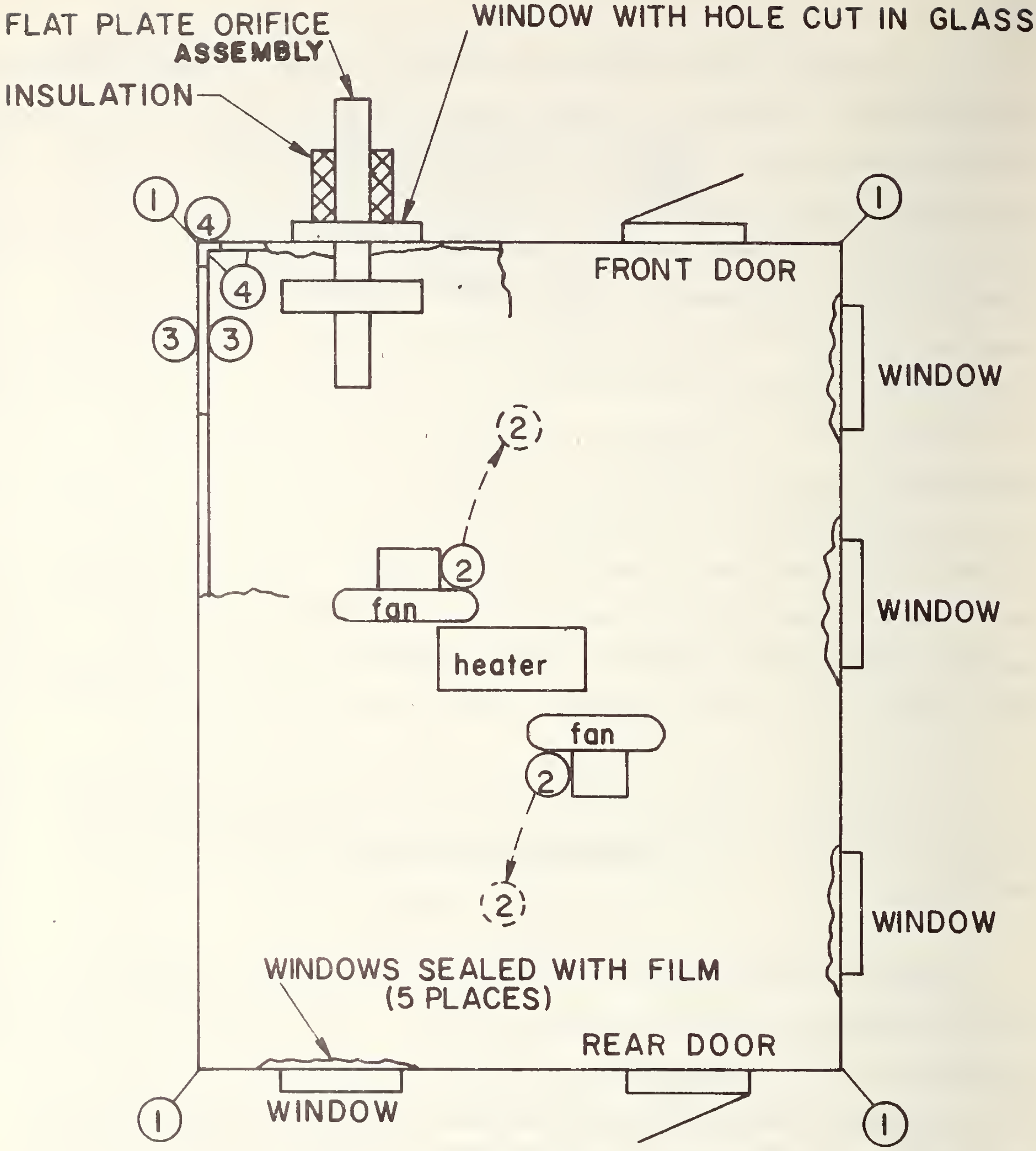
6.1

The purpose of this test was to measure the heat transfer rate for this building. Because the window design was to be changed on later model buildings the windows were left sealed with the polyethylene film so that their infiltration effect would not be present in the results. This will allow comparisons with later model building tests by sealing the windows in the same manner. The closed doors were left unsealed. Exterior air temperature was held at about 5°F and was measured with a four-in-one averaging thermocouple. The interior air temperatue leveled out at about 65°F as measured by a two-in-one air thermocouple. This measurement was made on the air return side of two fans which circulated air around an electric resistance heater located in the center of the building. The heat input was recorded on two 240-volt single phase watt-hour meters. Power to the fans was included in the measurement. The watthour meters were calibrated under load conditions. The steady-state heat input at the above temperature condition was 30,540 Btu per hour.

The air-flow orifice assembly was left in place in the window during the test, however, it was insulated on the section outside of the building.

Several thermocouples were positioned at various locations for future compatison with other constructions. The location of thermocouples and other arrangements are shown schematically in figure 14. The temperature and heat input were held steady for 63 hours before the data used for computations were taken. After the basic heat loss test data had been collected, an additional test with the interior air thermocouples moved to a better averaging location was run. The interior air thermocouples were moved from the air inlet side of the floor fans to a location approximately five feet above the floor and along the center line of the building about one-third of the building length from each end. The new locations gave an average temperature 2°F lower than the temperature indicated by the thermocouples when

HEAT TRANSFER TEST FLOOR DIAGRAM
OF A MARK III RELOCATABLE HOUSE



1 -- Locations of four in one outside air thermocouples, held by wire halfway up the outside wall on a six-inch diagonal from the corner.
2 -- Two-in-one inside air thermocouples on fans.
3 -- Thermocouples on center of panel surface inside and outside.
4 -- Thermocouples on corner and eave extrusions

Figure 14.

they were on the fan inlets. An adjustment to account for this difference was included in the building heat loss calculations.

6.2 Heat Transfer Test Results

Total building heat transfer rate for the Lewis building as it was assembled in the environmental lab using two of a possible three bay construction and under the conditions outlined above was 527 Btu/hr (°F) with the windows sealed with polyethylene film.

6.3 Discussion of Results

The heat transfer rate for this building expressed in accordance with FHA minimum property standards was 57 Btu/hr per square foot of floor area, as assembled and tested in the environmental lab. This value was arrived at by referring to the FHA Minimum Property Standards Handbook for One and Two Living Units in the section for buildings heated by other than electricity [4]. These standards refer to living spaces heated to 70°F and for total floor area measured to the outside of the exterior walls, and recommend a maximum of 50 Btu/ft^2. The 57 Btu/hr ft^2 value for the Lewis building is slightly higher than the FHA suggested maximum of 50 Btu/hr ft^2. It should also be noted that the Lewis building's heat transfer coefficient would have been higher if the windows had not been covered with polyethylene film as noted earlier in this section.

The temperature observed on the inside surfaces of the aluminum frame extrusions indicated that moisture condensation could be a problem at temperature conditions similar to those in the test. The inside surface temperature of one extrusion, for example, was below 40°F, with an adjacent interior air temperature of about 65°F.

7. Thermal Performance Evaluation

7.1 Evaluation Objective

The purposes of this series of tests was to evaluate the probability of condensation occuring on the interior of aluminum members of the building and relating the thermal performance to the heat losses from the structure under winter climatic conditions of the temperate

regions of the United States. Of special concern is moisture condensation on the surfaces of aluminum extrusions used as structural members. These extrusions form a preferred heat flow path from the inside to the outside by means of highly conductive aluminum and give a very small temperature difference from inside to outside whereby the temperature on the inside surface may be lower than the desired dew-point temperature in the structure. A discussion of alternate extrusions such as plastics is included.

7.2 Thermal Performance of Prototype Building

7.2.1 General

The prototype building tested at the National Bureau of Standards has an inside effective area of approximately 2252 square feet for which 60 square feet was in five single pane windows. The projected inside area of aluminum through members was 103 square feet. This area is based on the flange area assuming that the flange forms a highly conductive heat flow path to the web of the extrusion. The outside projected area (about 160 square feet) is considerably greater when considering that the flange areas for the wall-corner, wall-floor and roof peak are two to three times greater. In addition the floor rests on four inch aluminum I-beams over a considerable area. These I-beams will act like fins promoting heat losses from the structure.

7.2.2 Assumed Conditions

The assumed conditions for this study are taken from the Handbook of Fundamentals of the American Soceity of Heating, Refrigerating and Air-Conditioning Engineers. For a 15 mph wind outside the surface conductance is 6 Btu hr^{-1} ft^{-2} F^{-1} and a value for the inside surface is 1.46 Btu hr^{-1} ft^{-2} F^{-1}. For these conditions U_f = 1.13 for single pane windows and 0.6 Btu hr^{-1} ft^{-2} F^{-1} for double pane windows. From tests performed on a material similar to the three inch thick sandwich honeycomb panel construction, a value for the conductance is 0.22 Btu hr^{-1} ft^{-2} F^{-1}, giving U_w = .185 Btu hr^{-1} ft^{-2} F^{-1}. The heat loss through the panels and single pane windows for a degree temperature difference between inside and outside is then,

$$.185 \times 2089 + 1.13 \times 60 = 454.27 \text{ Btu hr}^{-1} \text{ F}^{-1}$$

7.2.3 Heat Transfer in Extrusions

The calculation for heat losses through the aluminum extrusion has no amenable solution and is further complicated by the fact that the flanges of the extrusions have a thermal contact with the inside and outside surfaces of the aluminum skin of the honeycomb panels. The linking of the highly conductive aluminum skin with the preferred heat flow path of the extrusions indicates a complex heat flow problem for which intuitive approximations are necessary for the purposes of this report.

The aluminum alloy has a thermal conductivity of about 100 Btu hr^{-1} ft^{-1} F^{-1}, and if the heat flow from the aluminum skins of the panels is neglected the transmission coefficient for the extrusions is approximated by:

$$U_e = \frac{1}{\frac{1}{1.46} + \frac{103}{6\text{x}160} + \frac{.125}{12\text{x}100} + \frac{103\text{x}3}{5\text{x}12\text{x}100} + \frac{103\text{x}.125}{12\text{x}160\text{x}100}} = 1.18 \text{ Btu hr}^{-1}\text{ft}^{-2}\text{F}^{-1}$$

where the thickness of the web and flange is .125", the length of the web is 3" and crossection area of web is 5 square feet. Under the above assumptions, the heat flow through the extrusions for one degree temperature drop is 1.18 x 103 = 121.54 Btu $\text{hr}^{-1}\text{F}^{-1}$.

7.2.4 Heat Losses Due to Air Change

Here it is assumed that the number of air changes taking place per hour is 1.5. For a structure volume of 5400 cubic feet, the heat loss for one degree temperature difference between inside and outside is 1.08 x 1.5 x 5400/60 = 145.8 Btu hr^{-1} F^{-1}.

7.2.5 Total Heat Loss

The sum of the calculated heat losses is 454.27 + 121.54 + 145.8 = 721.6 Btu $hr^{-1}F^{-1}$. For a 75°F inside air temperature and a 5°F outside temperature the heat loss from the structure is 50,513 Btu hr^{-1} or about 79 Btu hr^{-1} per square foot of floor area.

The structure with double pane windows gives a calculated heat loss of 689.8 Btu $hr^{-1}F^{-1}$ and for the conditions cited above the heat loss is 48,286 Btu hr^{-1} or about 75 Btu hr^{-1} per square foot of floor area.

The calculated heat transfer rates of 79 Btu hr^{-1} and 75 Btu hr^{-1} per square foot of floor area are higher than the actual laboratory test value of 57 Btu hr^{-1} per ft^2 reported in Section 6.3. The assumption of 1.5 air changes per hour in calculating heat losses could be one reason for the calculated and test value discrepancy. The actual building was not pressurized during the heat transfer test and had polyethelene film on all windows. Assuming an air leakage rate of 0.5 air changes per hour instead of 1.5 results in a heat transfer rate of 63.4 Btu hr^{-1} per ft^2 which is in closer agreement with the 57 Btu hr^{-1} per ft^2 test value.

7.3 Plastic Extrusions

Assuming that it is feasible to replace the aluminum extrusions by using plastic extrusions, the thermal conductivity of plastics is about .333 Btu hr^{-1} $ft^{-1}F^{-1}$. The transmission coefficient becomes .253 Btu $hr^{-1}F^{-1}$ and the heat loss for one degree temperature difference is 26 Btu $hr^{-1}F^{-1}$ which is a reduction of 95 Btu $hr^{-1}F^{-1}$ from the use of aluminum. The total calculated heat loss for the building is then 626.1 Btu $hr^{-1}F^{-1}$ (68.5 Btu hr^{-1} per square foot of floor area with a 70°F temperature drop).

7.4 Interior Condensation

Moisture in air will condense on surfaces it comes in contact with if the dew point temperature of the air is greater than the temperature of the surface. Interior surfaces that will be subjected to possible condensation are windows and the flanges of the aluminum extrusions. Based on the interior surfaces temperatures and an inside temperature of 75°F, figure 15 is a plot of the dew point temperature at which condensation will take place versus the outside air temperature for the aluminum extrusion and single and double window. The plastic extrusion is not considered as a possible surface for condensation.

7.5 Conclusions and Recommendations

For comfort conditions in living spaces during the winter a dry bulb temperature of 75°F and relative humidity of 30 percent or less is acceptable.

Figure 15 shows that it is not possible to maintain 30 percent relative humidity in the building for outside air temperature below 34°F because at lower outdoor temperatures condensation will form on the inside surfaces of the aluminum extrusions and will continue to form until an equilibrium relative humidity is attained somewhere below 30 percent. This problem will not exist for the plastic extrusions because condensation will form on the single or double pane windows in preference. Double pane windows would allow a 30% indoor relative humidity to be maintained for outdoor temperatures down to about -5°F.

The calculated heat losses for the Mark III building are believed to be conservative values in that some of the possible sources of heat loss were neglected such as the heat losses by the aluminum I-beams supporting the building in thermal contact with extrusions and aluminum skin of the floor and the heat flow paths of the aluminum skins on the inside and outside of the panels which are in thermal contact with the extrusions.

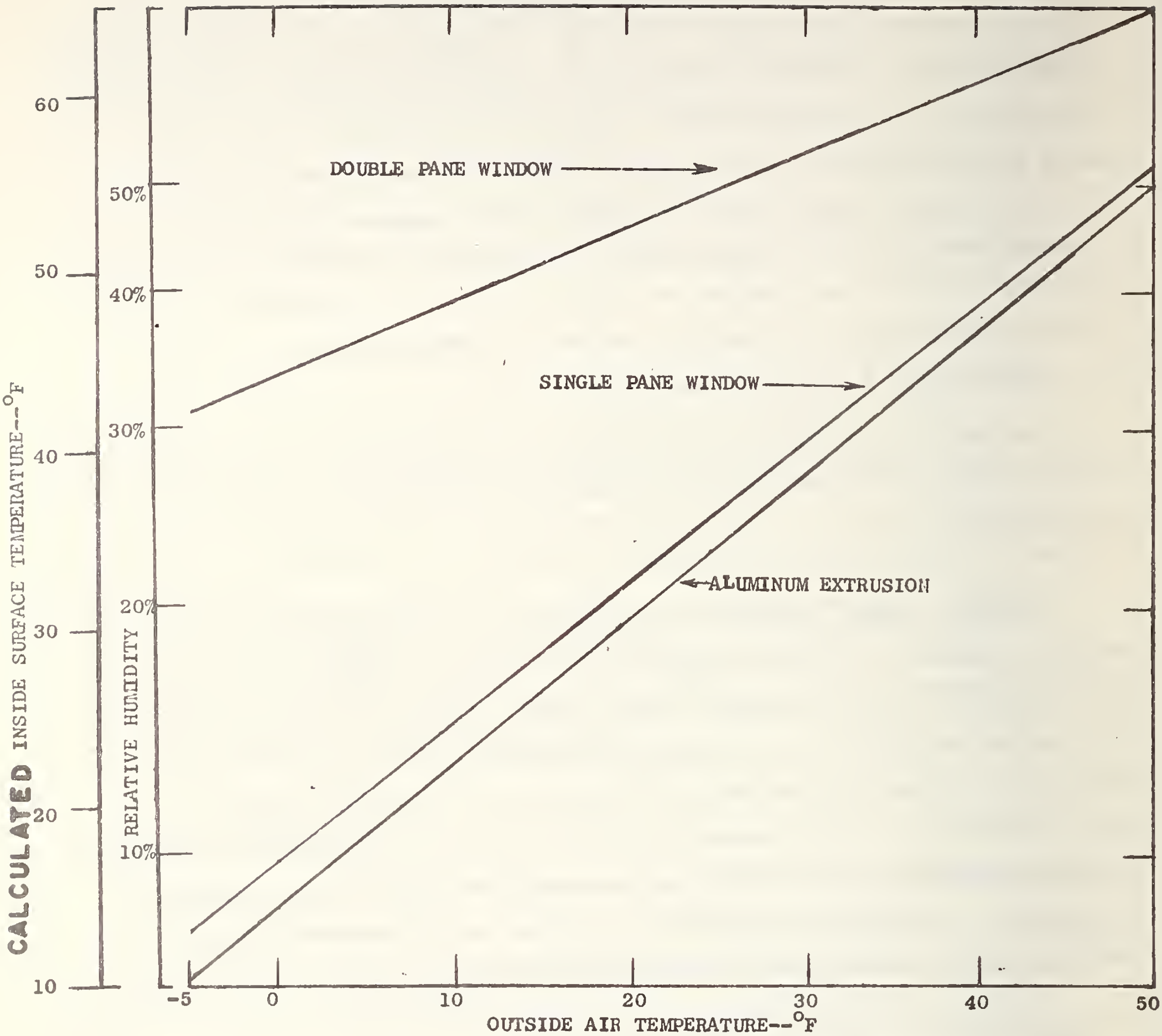


Figure 15. Temperature of Interior Window and Extrusion Surfaces with 75°F Inside Air Temperature

To relate the thermal performance of this building to winter climatic conditions of the temperature regions of the United States, the minimum property standards for similar types of housing have been set forth by the Federal Housing Administration.[4] Citing from paragraph 714-31, "The total calculated heat loss of the living unit shall not exceed 50 Btu hr^{-1} per square foot of the total floor area of the space to be heated to 70°F measured to the outside of exterior walls." Using this criterion, a floor area of 640 square feet and the calculated heat loss, the recommended outside design temperature is

$$T_o = 70 - \frac{640 \times 50}{721.61} = 25.6°F$$

On this basis, the building is suitable only for the southern regions of the United States. If it could be assumed that the building were constructed with double pane windows and plastic extrusions, the calculated heat loss is 584.2 Btu $hr^{-1}F^{-1}$ and the outside design temperature T_o = 16°F. This extends the suitable range for this building.

8. Discussion and Conclusions

Observations during the smoke tests revealed the doors and windows as the areas of major air leaks. These observations are supported by the reductions in air flow shown in Table A and Figure 11 when the doors and windows were sealed. There were no other single large leakage points. One or two places where the edges of a panel had been damaged in handling or assembly showed slightly higher smoke leakage than undamaged sections.

There was no change in the basic building leakage characteristics due to installation of the racking equipment to apply the simulated wind load force. This can be seen by comparing the standard air flows shown in figures 11 and 13 for the tests with only the windows sealed.

From Table B which lists air flow while the racking loads are applied to the building, it is significant that at a constant air pressure difference there was no appreciable increase in the total air leakage for a building racked to 1.13 times the original scheduled design load of 25 lb per ft^2.

Air leakage rates at 0.10 inches W.G. before installation of the racking apparatus ranged from 196 cfm with doors and windows unsealed to 108 cfm when they were sealed. When only the windows were sealed, the leakage rate was 171 cfm. After installation of the racking apparatus, with the windows sealed, the leakage rate at 0.10 inches W.G. was 176 cfm before the house was racked. During the racking tests with the windows sealed, the air leakage at 0.10 inches W.G. ranged from 175 to 182 cfm. The careful caulking of the panel-to-frame joints both inside and out is believed to be a factor in this performance.

The heat loss of this test building 527 Btu/hr (°F) was no doubt influenced by the heat conduction of the aluminum extrusion members. By testing a similar-size building with the windows sealed as they were in this test, the comparative effect of using extrusions with improved heat transfer characteristics can be determined.

All of the measurements in this report are primarily useful for such comparison purposes where improved structures are similarly tested.

9. References

1. Reichard, T.W. and Leyendecker, E.V., "Test and Evaluation of the Prefabricated Lewis Building and its Components, Phase I Part 1, Evaluation of Sandwich Panel Components," National Bureau of Standards, Report 10163, March 1970.
2. Reichard, T.W. and Leyendecker, E.V., "Test and Evaluation of the Prefabricated Lewis Building and its Components, Phase I Part 2, Full-Scale Building Tests," National Bureau of Standards Report 10164, February 1970.
3. The American Society of Mechanical Engineers, Flow Measurement, Power Test Codes (PTC 19.5; 4-1959), Chapter 4 (1959).
4. Federal Housing Adminstration Minimum Property Standards for One and Two Living Units, (FHA No. 300-1965) Paragraph 714-3.1 printed by the U.S. Government Printing Office, 1966.

The policy of the National Bureau of Standards is to encourage and lead in national use of the metric system, formally called the International System of Units (SI).

These tests were performed and the report was prepared prior to the National Bureau of Standards commitment to the SI presentation of data. This publication uses customary English units, so the reader interested in conversion to SI units is referred to:

(1) NBS SP 330, 1972 Edition, "The International System of Units"

(2) E380-74 ASTM Metric Practice Guide (American National Standard Z210.1)

The following table shows conversion factors for the units used in this report.

Quantity	To convert from	To	Multiply by
Length	inch	meter (m)	2.540×10^{-2}
	foot	m	3.048×10^{-1}
Area	sq.ft.	m^2	9.290×10^{-2}
Volume	cu.ft.	m^3	2.832×10^{-2}
Temperature	F	Celsius(C)	$t_c=(t_f-32)/1.8$
Pressure	inch of water (60F)	N/m^2(Pa)	2.488×10^2
	lb/ft^2	N/m^2(Pa)	4.788×10
Velocity	mph(US Statute)	m/s	4.470×10^{-1}
Power	Btu/h	W	2.931×10^{-1}
Time	minute	second(s)	60.0
Conductivity	Btu/(hr.ft.°F)	w/(m.K)	1.730
Heat Flux	$Btu/(hr.ft^2)$	w/m^2	3.155

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15. SUPPLEMENTARY NOTES

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report presents the findings of air leakage and heat transfer tests of a Mark III relocatable building at the National Bureau of Standards, Building Environment Division, for the U.S.Department of the Navy. Quantitative and qualitative (smoke trace) air leakage tests with the building pressurized, and the heat transfer test, were performed with the building erected in an environmental laboratory. The quantitative air leakage tests were performed in two phases. One was with the building racked to simulate a wind load and the other was without racking. The building was of prefabricated honeycomb panel construction using aluminum skins. Included are photographs of the building and test equipment and tables and charts showing the magnitude of air leaks at the windows and doors. Racking had negligible effect on the air leakage rate.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)*

Air leakage of buildings; building heat transfer; honeycomb panel construction; relocatable buildings; wind-load racking.

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